EDITORIAL

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EDITORIAL

The silver anniversary of the Chernobyl accident. Where are we now?

On 26 April 1986, a test on an electrical control system at the Chernobyl nuclear power station in present-day Ukraine caused a steam explosion which resulted in a substantial fraction of the radioactive material contained within one of the four RBMK reactors at the site being ejected into the atmosphere, in what is the worst ever accidental release of radioactivity into the environment [1–3]. Of those emergency workers dealing with the immediate aftermath of the accident, 134 developed acute radiation sickness which resulted in 28 deaths in 1986, with a further 19 of these workers dying in the following 18 years (although not necessarily as a direct consequence of their exposure to radiation) [2].

The total activity released to the environment by the accident was ~14 EBq, about half of which was due to noble gases, and notable releases also occurred of ~85 PBq of $^{137}$Cs and particularly of ~1.8 EBq of $^{131}$I [1–3] (~1000 times greater than the activity of $^{131}$I released during the Windscale reactor fire of 1957 [4]). Significant releases of radioactivity persisted over ten days, until the fire in the graphite moderator of the reactor was brought under control, which caused especially heavy contamination in areas of present-day Ukraine, Belarus and the Russian Federation [1–3]. More widespread lesser contamination occurred throughout most of Europe, the local levels determined by the patterns of winds and rainfall in the days during and following the release [1].

A group of senior scientists from the Academy of Medical Sciences of the USSR produced a report on the predicted health consequences of the accident in mid-1989, which was published in the Journal of Radiological Protection (JRP) in 1990 [5]. It stated in the abstract:

'A statistically significant excess over the spontaneous level is unlikely to be detectable for these effects [cancer, hereditary effects and teratogenic effects]. A possible exception may be thyroid disorders.'

These authors estimated that the collective thyroid dose in the then USSR was $45.7 \times 10^4$ man.Sv, and that during the 30 years following the accident 452 additional thyroid cancers would arise from this level of exposure [5]. It is of interest that the scientific establishment in the USSR was publicly predicting in 1989 that an excess of thyroid cancer would occur as a result of the intake of radioisotopes of iodine released during the accident, and that this excess might be detectable statistically. By way of comparison, in 2006 Cardis et al [6] estimated that 460 additional cases of thyroid cancer up to 2005 in the moderately and heavily contaminated areas of the former USSR could be attributed to radiation exposure from the Chernobyl accident, although the uncertainty of this estimate is a factor of around four.

Of course, it is the pronounced excess of thyroid cancer among those exposed to radiiodine as children while living in the heavily contaminated areas of the former USSR that is the dramatic and unambiguous mark of the accident upon the exposed population [1–3, 7, 8]. Many children in these areas received thyroid doses approaching and in excess of 1 Gy, mainly from $^{131}$I, and more than 4000 cases of thyroid cancer diagnosed before the mid-2000s can be attributed to the accident [2, 3]. It had been known for some time that the thyroid gland
in infancy and early childhood is particularly sensitive to radiation-induced cancer—thyroid cancer was the first solid tumour found to be in excess in the Japanese atomic bomb survivors exposed as children [9]—but when the initial sign of additional Chernobyl-related cases started to appear in the early-1990s it was broadly greeted with a mixture of surprise and scepticism, although the existence of this excess is now beyond reasonable doubt [1–3]. However, the number of excess thyroid cancers actually observed up to the mid-2000s is notably larger than the estimate given by Cardis et al in 2006 [6]; the reason for this is unclear, particularly since the current risk models for radiation-induced thyroid cancer would appear to be broadly compatible with risk estimates obtained directly from those exposed to radioiodine released from Chernobyl [10].

The BEIR VII model of the risk of radiation-induced thyroid cancer [11], based upon studies of groups of children exposed to external sources of radiation [12], predicts an excess relative risk (ERR) coefficient (the proportional increase in risk per unit thyroid dose) of \(\approx 10 \text{ Gy}^{-1}\) for exposure in early childhood, i.e. a thyroid dose of 1 Gy produces around a tenfold increase in thyroid cancer risk compared to the background risk, which then falls away with age at exposure such that it is \(\approx 2 \text{ Gy}^{-1}\) at an age at exposure of 20 years. Of importance in this risk model is that this is the lifetime ERR, i.e. the proportional increase in risk persists throughout the remainder of life. Given the rise in the background risk of thyroid cancer with increasing attained age—in females in the UK the incidence rate rises to a plateau of around 6 cases per \(10^5\) at an attained age of 40 years and in males there is a steady rise to this level of incidence rate in the elderly (http://info.cancerresearchuk.org/cancerstats/types/thyroid/incidence/#age)—the predicted excess of thyroid cancer cases will grow with the ageing of the population exposed in childhood. If our current risk models are right about the absence of attenuation of the ERR with attained age (or time since exposure) then we have seen up to now only the tip of the iceberg and many thousands of cases of thyroid cancer are still to come among those heavily exposed to radioiodine in childhood. It will be crucial to determine just how the number of excess cases evolves to enable a revision of predicted numbers to be made if any attenuation of the ERR with time is observed—if any revision is actually required. A dose-related excess of thyroid cancer still exists in the Japanese atomic bomb survivors 55 years after exposure [13], although there is some evidence of a decrease in the ERR with time [14].

A case-control study of thyroid cancer among those exposed in childhood in the heavily contaminated regions of Belarus and Russia [15] and a cohort study of young people resident in the heavily contaminated areas of Ukraine at the time of the accident [16], using largely reconstructed thyroid dose estimates, have found ERR coefficients that are broadly compatible with that obtained from a pooled analysis of seven externally irradiated groups of children [10]. There is some evidence for a risk modifying effect of iodine deficiency prior to exposure (which increases the risk) and of stable iodine supplementation after exposure (which decreases the risk), although this requires confirmation [10]. There are other uncertainties that complicate the picture, such as the effect of short-lived radioisotopes of iodine (e.g. \(^{133}\)I) and the influence of screening for thyroid disease in the heavily exposed populations [10], and studies continue (e.g. the recently reported study of thyroid cancer screening in Belarus [17]). An exposure-related risk of thyroid cancer among those resident in the heavily contaminated areas of the former USSR at the time of the accident as adults or who were in utero is not clear [10].

As for thyroid diseases other than cancer, benign nodules and cysts show a dose-related excess among the Japanese atomic bomb survivors 55 years after exposure [14]. There is some evidence of a dose-related excess of benign thyroid tumours in the Ukrainian cohort of young persons [16], and it does seem likely that there will be a substantial excess of cases of non-malignant thyroid disease as a result of exposure to radioiodine released from Chernobyl.

Outside the heavily contaminated areas of the former USSR the Chernobyl-associated risk
of thyroid disease becomes less clear [18]. Of course, dilution and the half-life of \(^{131}I\) of eight
days will reduce the dose received by the thyroids of children outside these areas, but studies
would be worthwhile, if difficult to interpret reliably.

As for cancers other than thyroid cancer that might be in excess as a result of Chernobyl
contamination, there is little firm evidence of an effect of radiation exposure from the accident.
Childhood leukaemia is an obvious candidate for an excess of cases, and some evidence does
exist for an effect of Chernobyl in the heavily contaminated regions of the former USSR
[19], but control selection problems could be responsible for an association that appears to be
largely confined to the Ukraine [20]. Similarly, there is some evidence for an excess of breast
cancer in the heavily contaminated regions of Belarus and Ukraine [21], which requires further
investigation to be reliably interpreted.

The registration rate of congenital malformations in Belarus has been been steadily
increasing during the 1980s and 1990s, but in both the high contamination and the low
contamination areas of the country, suggesting that generally improving diagnosis and
registration may be responsible [22]. A recent study in a heavily contaminated area of
Ukraine has suggested, however, that an unusual pattern of congenital malformations could be
associated with the accident [23], although further investigations are required before a reliable
conclusion can be drawn from these findings.

Some 600,000 people (‘liquidators’) were involved in emergency and recovery work
following the Chernobyl accident, and \(\sim 240\,000\) of these worked during 1986–7 when exposures
would have been highest [1, 2, 7]. These liquidators offer an opportunity to study the health
effects of protracted exposure to low or moderate levels of radiation. However, studies
of Chernobyl liquidators are not straightforward. For example, many doses have to be
reconstructed, and uncertainties are substantial. Further, interest in these workers is likely to
have led to better ascertainment of health effects among the liquidators than in the population
as a whole, leading to a distinct possibility of bias if a comparison of a particular disease rate
in a group of liquidators is made with that for the general population, and the results of such
studies must be treated with considerable caution.

Leukaemia would be predicted to be the first cancer to show a radiation-related excess
among the Chernobyl liquidators. To overcome ascertainment bias, nested case-control
studies have been conducted among workers from the Ukraine [24] and among those from
other countries of the former USSR (Russia, Belarus and the Baltic states combined) [25].
Such studies consider both cases of a particular disease and controls without the disease
drawn from a specified group of liquidators, to avoid comparisons involving the general
population. Considerable effort has been expended on these studies, e.g. on dosimetry and
case identification.

In the Ukraine a statistically significantly raised ERR coefficient was found for all
leukaemias combined [24], while in the group of other countries a significantly raised ERR
coefficient was found for leukaemia, non-Hodgkin’s lymphoma (NHL) and a group of other
haematological malignant diseases combined [25]. However, interpretation is not simple since
in both studies the ERR coefficient for chronic lymphocytic leukaemia (CLL) is raised to around
the same level as for leukaemia excluding CLL [24, 25], and in the group of other countries the
ERR coefficient for NHL is also raised [25]—other studies of exposed groups suggest that CLL
and NHL are not as sensitive to radiation-induction as leukaemia excluding CLL [11], so the
pattern of results from these two studies is rather unusual and further investigation is required
to properly understand the findings. However, these nested case-control studies do suggest
a radiation-related risk of leukaemia among the liquidators, albeit that caution is required in
interpretation.

A study of Russian liquidators has suggested a radiation-related risk of blood circulatory
system disease [26]. Interpretation of this finding is difficult because of the influence of other factors, but it does add to growing epidemiological evidence that low and moderate doses of radiation increase the risk of heart disease and stroke [27]. Liquidators have also experienced an excess risk of cataracts of the lens of the eye [28], which adds to the evidence that cataracts and eye lens opacities can be induced by lower levels of radiation exposure than previously thought [29].

So, the liquidators provide a basis for the study of the effects of protracted exposure to radiation and investigations should certainly continue. However, the difficulties associated with such studies should not be underestimated, and early studies comparing health outcomes among the liquidators with those in the general population could well be affected by ascertainment bias and need to be viewed in this context.

As far as the psychological effects of the accident are concerned, there is evidence for raised rates of depression, anxiety and medically unexplained physical symptoms in exposed populations, especially (and understandably) among mothers of young children; but rates of diagnosable psychiatric disorders do not appear to be elevated [30]. There is also evidence of a high rate of suicide among Estonian liquidators [31].

It must be appreciated that studies of the potential effects of Chernobyl contamination in the countries of the former USSR are susceptible to many biases and confounding factors, not least because of the impact upon health of the various socio-economic crises that have occurred, including the break-up of the USSR itself. So, whereas mortality rates for men and women in Finland and the Czech Republic (treated as reference countries) showed a steady decline during the 1990s, in Russia there was a pronounced rise of the overall mortality rate to a peak in 1994 followed by a decrease and then another increase in the late-1990s in all regions of Russia (including the Far Eastern Region which was hardly affected by Chernobyl contamination) [32]. These peaks have been linked to increased alcohol consumption following socio-economic crises [33]. This background of major influences upon the health of the Russian population (and undoubtedly the populations of the other countries of the former USSR) serves to illustrate the problems of trying to extract a signal of the Chernobyl accident from a baseline rate that is variable due to the substantial impact of other factors.

What, then, is to be made of the book by Yablokov et al published in December 2009 as volume 1181 (in all, 343 pages) of the Annals of the New York Academy of Sciences [34]? The book—‘written by leading authorities from Eastern Europe’—draws heavily on the Russian and Ukrainian language literature and concludes that previous assessments of international bodies have grossly underestimated the health impact of the Chernobyl accident; Yablokov et al suggest that several hundred thousand people have already been killed by the accident. Duncan Jackson has provided an insightful review of the book by Yablokov et al in this issue of JRP [35], and he draws attention to a number of oddities in the book, which indicate that circumspection is required in drawing inferences from its contents. The views of Yablokov et al should be given proper consideration, and there may well be health effects arising from the Chernobyl accident that are not presently recognised by mainstream science; but the plethora of adverse health effects claimed to be a consequence of the accident makes one wonder where to start, and the tone of the book in emphasising an obvious international conspiracy to hide the truth leads to an uneasy feeling about the intentions of the authors. Perhaps the major problem is that the book—a direct translation from the original 2007 Russian version that does not appear to have undergone any peer review prior to the publication of the English version—is published in the Annals of the New York Academy of Sciences with no accompanying critical commentary that might allow a reader unfamiliar with the literature on the health effects of the Chernobyl accident to gain some perspective as to how to approach the material to be found in the book. This is both puzzling and unfortunate, since the views
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of Yablokov et al are likely to be regarded by most experts in the field as representing one rather extreme position. Perhaps this is behind the somewhat inscrutable statement later issued by the New York Academy of Sciences (http://www.nyas.org/AboutUs/MediaRelations/Detail.aspx?cid=16b2d4fe-f5b5-4795-8d38-d59a76d1ef33) which states *inter alia:*

‘The expressed views of the authors, or by advocacy groups or individuals with specific opinions about the Annals Chernobyl volume, are their own. Although the New York Academy of Sciences believes it has a responsibility to provide open forums for discussion of scientific questions, the Academy has no intent to influence legislation by providing such forums. The Academy is committed to publishing content deemed scientifically valid by the general scientific community, from whom the Academy carefully monitors feedback.’

The Academy would have been wise to anticipate the hostile reaction to its publication of the book that is implied by this statement by commissioning a commentary to accompany volume 1181 of its *Annals* to provide some perspective as to whether its contents were indeed ‘deemed scientifically valid by the general scientific community’.

At the time of writing this editorial (early February 2011) the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) is intending to publish imminently a report on the latest evidence of health effects resulting from the Chernobyl accident (http://www.unscear.org/unscear/en/chernobyl.html), which will make interesting reading. Meanwhile, the Agenda for Research on Chernobyl Health (ARCH) project has recently submitted to the European Commission a proposal for a strategic research agenda, outlining a long-term plan for research into the health consequences of irradiation from the Chernobyl accident. The ARCH Core Group has written an article describing this proposal in this issue of JRP [36], and they argue for a significant research effort to determine the level of health effects that may be attributable to the Chernobyl accident. Indeed, there are surprising gaps in research related to radiation exposure from Chernobyl releases—what, for example, has happened to the European-wide study of childhood leukaemia that appears to have ceased follow-up in 1991 [37] (the follow-up of the Japanese atomic bomb survivors only started in 1950), or the equivalent study of leukaemia in infancy [38], or the European-wide study of childhood thyroid cancer [38]? Perhaps the research response to the ARCH proposal will help fill some of these gaps.

What have we learnt in the past 25 years of the health effects arising from radiation exposure due to the Chernobyl accident? There are some clear consequences: early deaths from acute radiation sickness among the emergency workers receiving high doses, a large excess of thyroid cancer among those heavily exposed to radioiodine as children, and psychological effects among those most affected by the accident. There are indications of other consequences: raised rates of leukemia among the liquidators, and increases in the incidence of childhood leukaemia and of breast cancer in the heavily contaminated areas of the former USSR. Further research should hopefully provide a clearer picture, but the difficulties of conducting studies that will provide reliable findings should not be underestimated. What is apparent is that studies carried out in regions that are susceptible to socio-economic instability are prone to influences that significantly complicate the interpretation of results—big signals of effects (such as the large excess of childhood thyroid cancer in the heavily contaminated areas of the former USSR) are readily apparent, but genuine smaller effects that may be detectable under more stable conditions could easily be hidden by the impact on health (and recording practices) of socio-economic turmoil, and this needs to be borne in mind when addressing past, current and future Chernobyl studies.
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